Energy Feedback at the City-Wide Scale

A comparison to building scale studies

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Dedication

This thesis is dedicated to my mom and dad.

Abstract

Climate change is a growing concern throughout the world. In the United States, leadership has so far failed to establish targeted reductions and agreement on mitigation strategies. Despite this, many large cities are taking on the challenge of measuring their emissions, establishing targeted reductions, and defining strategies for mitigation in the form of Climate Action Plans. Reporting of greenhouse gas (GHG) emissions by these cities is usually based on a one-time, annual calculation.

Many studies have been conducted on the impact of providing energy use data or feedback to households, and in some cases, institutional or commercial businesses. In most of those studies, the act of providing feedback has resulted in a reduction of energy use, ranging from 2% to 15%, depending upon the features of the feedback. Many of these studies included only electric use. Studies where all energy use was reported are more accurate representations of GHG emissions. GHG emissions and energy use are not the same, depending on the fuel source and in the case of this paper, the focus is on reducing energy use.

This research documents the characteristics of the feedback provided in those studies in order to determine which are most effective and should be considered for application to the community-wide scale. Eleven studies, including five primary and six secondary research papers, were reviewed and analyzed for the features of the feedback. Trends were established and evaluated with respect to their effectiveness and potential for use at the community-wide scale.

This paper concludes that additional research is required to determine if the use of energy feedback at the city scale could result in savings similar to those observed at the household scale. This additional research could take advantage of the features assessed here in order to be more effective and to implement the features that are best able to scale up. Further research is needed to determine whether combining city-wide feedback with feedback for individual energy users within the city, both residential and commercial, has an even greater impact on reducing energy use and lowering GHG emissions.

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Introduction

The primary causes and outcomes related to climate change are well documented, as are the actions required for mitigation (Boswell, *et al.* 2010). The only real question now is: *what are we going to do about it and when are we going to act?* The longer we wait, the greater the problem becomes (IPCC, 2013). Internationally, there is very little agreement regarding goals that all countries should adopt in order to mitigate climate change. Several large-scale conferences have produced very little progress towards getting the world's largest emitting countries to even agree on next steps. For example, the United States has not signed the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which has been signed by over 180 countries since the 1997 conference.

At the national level, few concrete steps have been taken. The United States Congress has the ability to establish targeted reductions and achieve them through a carbon tax or cap and trade system (Crane and Landis 2010). In addition, the President is able to directly limit emissions through the Environmental Protection Agency (EPA), since the Supreme Court decision in Massachusetts v. the EPA ruling established that GHG emissions are a pollution source that can be regulated (Cornell Law Journal, 2007). Neither of these actions is likely, given the current political climate. It is becoming clear that looking for one worldwide or national solution may not be the most feasible way to solve the problem.

In Minnesota, former Governor Tim Pawlenty created the Minnesota Climate Change Advisory Group (MNCCAG) which issued a final report in April 2008. The goal of the MNCCAG was to determine what actions are required to meet the state's 2007 Next Generation Energy Act legislation which mandates an 80% reduction from 2005 GHG emissions levels before the year 2050. According to the report's executive summary, the group approved 46 measures: 38 unanimously, four by super majority, and four by a simple majority (MNCCAG, 2008). The report concludes that the reduction goals for 2015 and 2025 could be reached if all 46 measures were implemented, starting immediately. Figure 1 (below) shows the projected GHG emissions in Minnesota , based on current legislative actions, the target based on our state's climate goal, and with the implementation of all 46 measures.

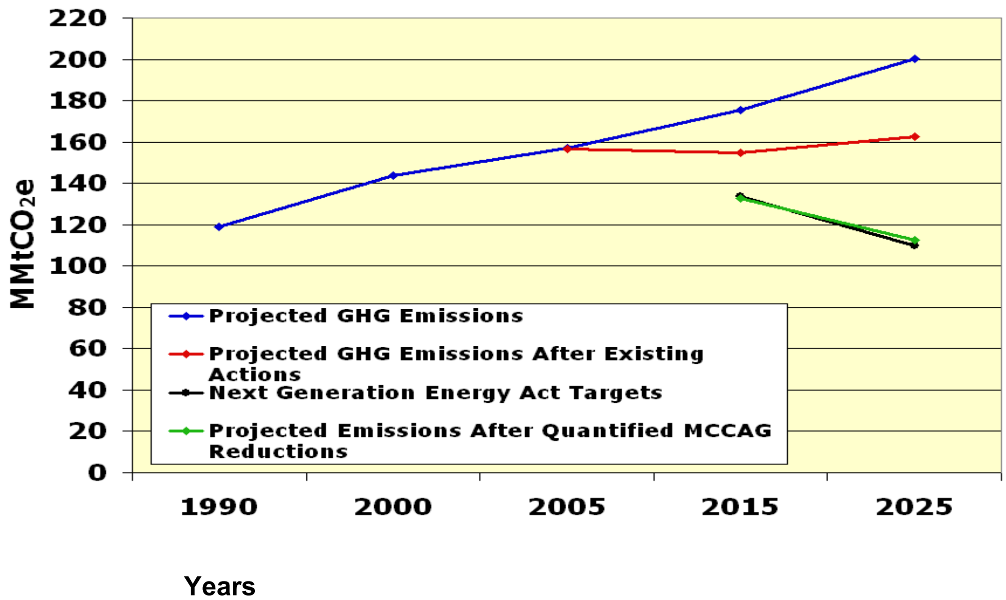

Figure 1. Business as usual and targeted emissions for Minnesota shown in $MMtCO_2e$ or million metric tons of carbon dioxide equivalent (MNCCAG Executive Summary, 2008)

Although the state has set goals and determined actions that will meet these goals, only a handful of those actions have been implemented. It is unclear why the state scale is slow to move or unable to take action, but the political landscape may be somewhat to blame. This lack of outcomes at the global, national, and statewide scales indicate that addressing GHG emissions at the city scale is an important next step in dealing with climate change (Hillman and Ramaswami, 2009). Over 1000 cities have signed on to the U.S. Mayors Climate Protection Agreement. Minneapolis, like many cities, has taken an active approach to Climate Action Planning (CAP), recently updating its GHG Inventory and CAP. Cities have unique advantages in approaching climate change, compared to states and nations. Their scale allows for the collection of consumption data such as energy use and transportation and, more importantly, they have the ability to implement changes that can produce the required reductions. Cities can have a large influence through policies such as land-use planning, building codes, planning and zoning ordinances, and green building policies. Additionally they can implement incentive programs, such as grants, tax abatement, and Tax Increment Financing (TIF).

It is also becoming clear that quantifying and monitoring the progress that is made at the scale of commercial buildings and households is important. Over the last 15 years, there has been a significant amount of research on the effect of providing energy use data, or feedback, primarily at the residential scale. These well-documented studies have included thousands of households from around the world (Fischer, 2008). Most of the studies involved computerized data, dating as far back as 1996 (Branden and Lewis, 1999). In all eleven studies included in Tables 1 and 2, feedback has been linked to some level of reduced energy use. In addition, there are a handful of studies that have evaluated the effect of providing feedback to commercial and institutional users. A recent EPA report of 35,000 commercial buildings currently entering total energy data (all fuels) into the Agency's Portfolio Manager system, demonstrated an annual savings of 2.4% per year, or a total of 7% over three years (EPA, 2012). Seen together, these results suggest that providing feedback does have an impact on energy use at the building scale.

Many cities are pursuing activities to become more sustainable and reduce energy consumption through programs such as Minnesota GreenStep Cities (MN GSC), without any way of tracking or reporting their progress. Cities need to measure results of mitigation efforts over time in order to know what actions are working (Boswell, *et al.* 2010). However, it is not clear from current research whether there would be any benefit to providing feedback about city-wide GHG emissions or energy use to residents and businesses.

The research reviewed for this paper primarily involved building energy use. Although GHG emissions are caused by many other factors, including transportation energy use, buildings create over 50% of all emissions and are typically metered at least monthly by utility companies (Ramaswami, et al. 2012). For the purpose of this research, "feedback" is defined as providing energy use data in a processed form, beyond typical monthly utility bills. In this case, "processed" means some additional information and or comparison to other data is included in the feedback.

Where feedback has been used to date, the energy use information has been provided with the express purpose of influencing decisions and consumption patterns. Since almost all of the known research is specific to households, residents have been the target audience. This research will consider how the results of providing feedback at the household and commercial building scale might make the city-wide energy feedback given to city staff, leaders, business owners, visitors, and residents more informative and effective. As a result of the proven track record for energy reduction by providing household energy use feedback, this study will also consider including specific feedback to households and businesses as a part of providing city-wide feedback.

Literature Search

The use of feedback as a means to increase awareness and decrease consumption of energy is evident in the energy literature at various scales. The literature demonstrates a range of savings in total non-transportation energy use at the household through organization scales, from 4% to more than 12.0% over time, based on various methods of providing feedback. One study indicates savings from 5% to15% for direct feedback and 0% to10% for indirect feedback (Janda, 2009). Direct feedback is best described as real-time information provided by using monitors and web-based data. Indirect feedback is not immediate (i.e. a monthly bill) and has been processed in some way (i.e. energy use is shown as compared to the average customer). Most of the studies are based on residential research, but at least one study makes the case for similar savings potential based on providing feedback in commercial buildings (Armel, *et al*. 2012). Armel (2012) documents pilot studies in commercial buildings where feedback specifically from plugload monitors led to the reduction of consumption by 15% to 40%. A recent study focused specifically on the amount of energy being used by equipment and supports the use of feedback to encourage reduced consumption (Metzger, *et al.* 2011). An office building in this study, showed a decrease in energy use of over 6% as a result of providing users with feedback of the energy used by the equipment in their office space. There is, however, limited research on providing feedback at the community or regional scale. Most of this research comes in the form of GHG emissions inventory studies (Ramaswami, *et al. 2008 and 2012*).

Most of the studies in the literature at the household scale demonstrate energy use reductions and emphasize the use of real-time, continuous feedback as the best way to influence consumption. There is a stated concern that behavior will not be self-sustaining and may require continuous intervention (He, *et al.* 2009). One possible reason that feedback may be helpful is the current lack of any kind of feedback in many cases (He, *et al.* 2009). Consumers are typically billed at the end of each month for the services rendered during that time. Providing direct feedback to the consumer, such as real-time meters, can bridge this information gap about how much energy is being used while they are using it (Janda, 2009). Methods that make electricity use visible and tangible, such as the power traveling through a cord to a device (Gustafsson, Gyllensward, 2005), appear to have some ability to influence usage. The feedback needs to be immediate and/or processed in some way in order for it to persist.

Household Scale

The most comprehensive assessment of feedback on energy consumption in the single family residential sector is a review of 38 feedback studies of domestic energy use over a 25-year period (Darby, 2006). This analysis of the various types of feedback (direct and indirect) concludes that providing feedback is an essential strategy in the reduction of energy use and therefore GHG emissions. Darby (2006) describes behavior that is formed over a three month or longer period as likely to persist. Fischer (2008) focuses on the various features of feedback including those that may increase its effectiveness. It contains a database review that includes 22 studies, compares their results, and identifies the method or type of feedback. The features include frequency, duration, comparisons, content, and medium. Fischer (2008) found that feedback does increase energy savings and that the other features that increase the likelihood of savings are if the feedback is:

- *based on actual consumption;*
- *given frequently over a longer period of time;*
- *provided with historical or normative comparisons; and*
- *presented in a clear and understandable way.*

Fischer (2008) identifies the energy utilities' motivation (willingness to provide the data) as a hurdle in gathering and disseminating information or data, and points out that many of the studies had very small samples. A review of twelve pilot studies analyzing the use of feedback on residential electricity consumption finds an average of 7% savings attributed to the act of providing feedback alone (Faruqui, *et al.* 2010). A study of nearly 200 households in the Netherlands reported very similar findings (Abrahamse, *et al.* 2007). The diagram below (Figure 2) shows a set of studies and the relationship between the type of feedback provided and the resulting energy reduction.

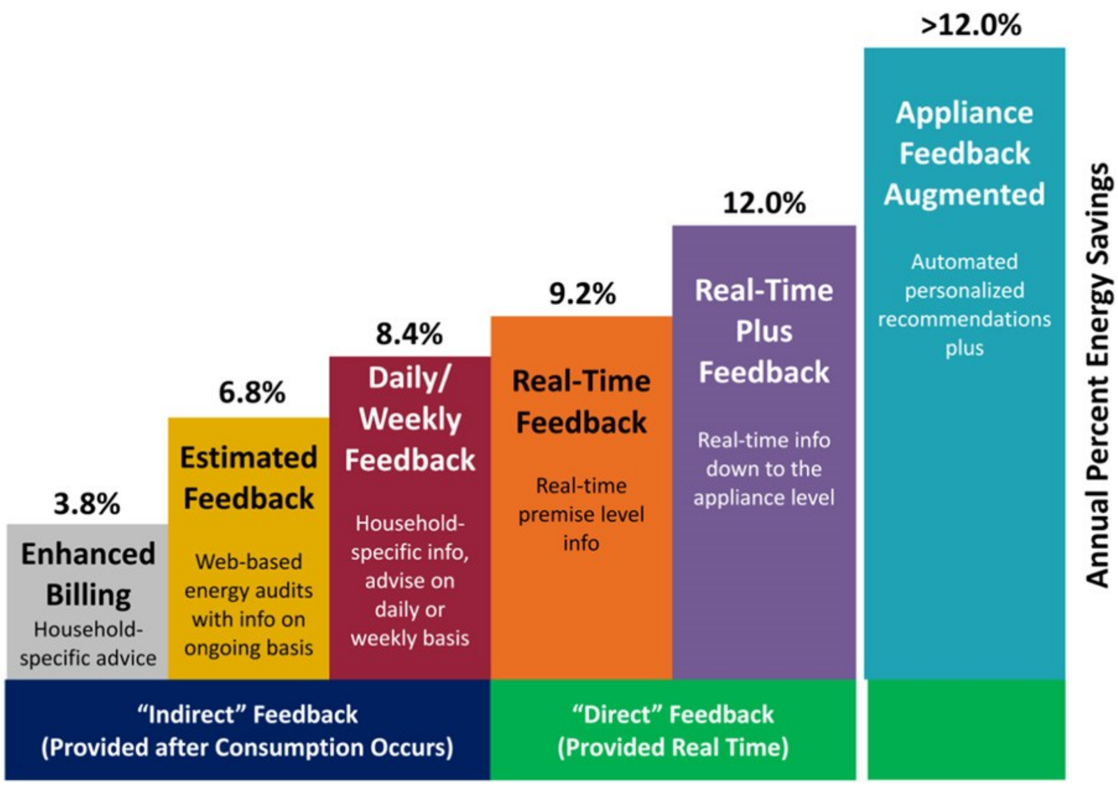

Figure 2. Residential savings due to energy consumption feedback: The five left-most bars are derived from 36 residential electricity studies between 1995 and 2010 (Ehrhardt-Martinez et al, 2010).

Much of the literature from the US and Europe covers various aspects of feedback on household consumption. One study in the United Kingdom covered 120 households over a nine-month period and compared weather-normalized use to the previous year's consumption (Brandon and Lewis, 1999). The study found income, socio-demographic status, and environmental attitudes contributed significantly to whether or not feedback made a difference. Brandon and Lewis (1999) concluded that while controlling these conditions, feedback significantly affects the quantity of energy consumed. Another UK study points out that historically, utility billing has been on a quarterly basis (versus monthly) basis, providing even less regular feedback (Roberts and Baker, 2003). To further remove direct feedback, the customer is increasingly paying on an automatic basis with direct debit. In this case, there is no need to open a bill or to write a check. Roberts and Baker (2003) conducted focus groups to ask customers what type of feedback they would like to receive and what they thought would be most effective; determining that graphic comparisons to "average" consumers would have the most influence. One residential study of providing energy use feedback focused on the influence of providing residents information about the energy consumption of their home appliances (Ueno, *et al.* 2006). The study documented resulting savings of 9% overall using PC-based feedback to the residents. The charts below (Figure 3.) illustrate the level of detail that can be provided in this type of feedback. Trends are shown in terms of day-to-day comparisons, percent of overall use, and averages over time.

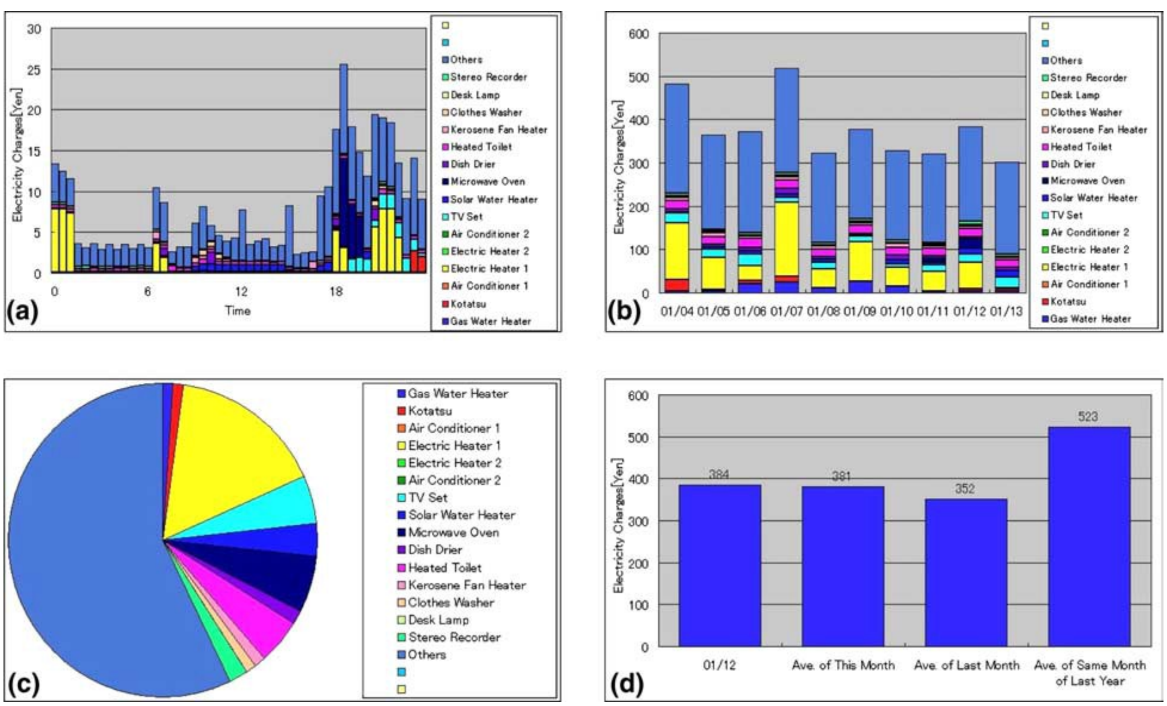

Figure 3. Real time web-based feedback example (Ueno, *et al,* 2005)

Another study analyzed non-price interventions, specifically behavioral approaches, in order to reduce energy consumption (Allcott and Mullainathan, 2010). For example, this study analyzed OPOWER, a company that helps utility companies to provide enhanced monthly energy bills that compare usage to the others in a similar billing group (Figure 4). The results consistently show a 2% consumption decrease in the residential electricity sector. The authors argue that scaling it up (providing it to all US electricity consumers) could reduce the total US carbon emissions from electricity use by 1%.

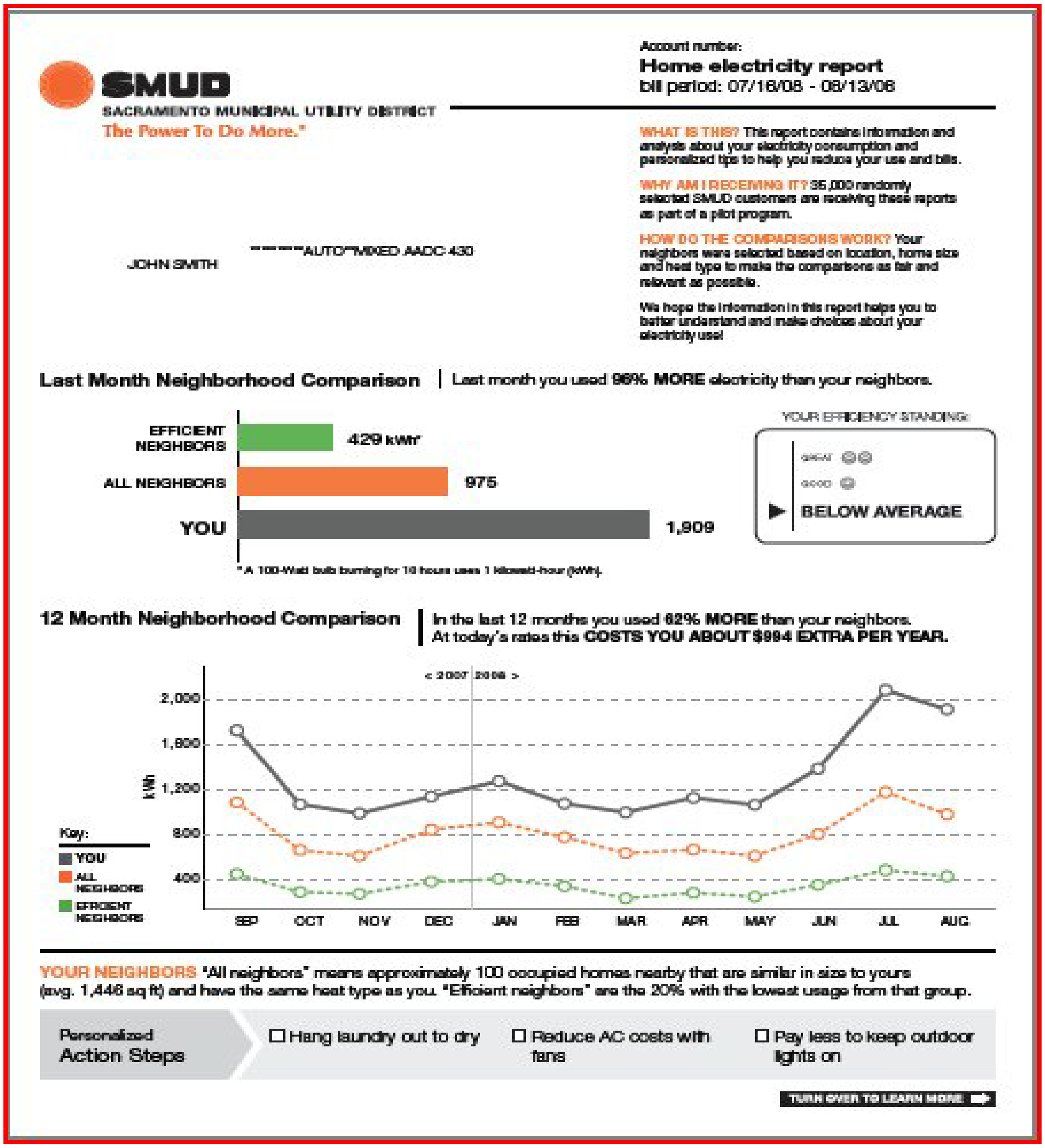

Figure 4: *OPOWER Home Electricity Report for Sacramento Municipal Utility District (Allcott and Mullainathan, 2010).*

Building Scale

A small amount of information was available on the subject of using feedback at a building scale other than in single family houses. Since commercial buildings account for approximately 20% of the total U.S. energy use and is a faster growing sector than residential, transportation, and industrial (Bin, 2012), understanding the impact of feedback in that sector is essential. Bin (2012) reviewed five case studies, evaluating each study's contents, format, and cost-benefit analysis. In three of the five cases—the Empire State Building, the US Capitol, and the Ministry of Energy, Mines and Petroleum Resource (MEMPR) of British Columbia, Canada—the use of feedback was specifically studied. In all of these case studies, the feedback was provided in real-time through an online dashboard and savings of up to 20% were reported. The feedback appeared to be directed at upper management and occupants, in order to drive energy reduction through peer pressure.

A study involving college dormitory buildings used feedback, education (information), and incentives which resulted in a 32% average reduction in electricity use (Peterson, *et al*. 2007). According to Peterson (2007), it is unusual for a student living in a dorm to receive any information regarding their resource use. The study conducted at Oberlin College suggests that the best way to provide feedback is in real-time, which enables the consumer to learn about the impact of their actions from trial and error. In this case, a two week campus-wide competition was held between dorm buildings. No specific suggestions on how students could conserve energy were provided. Occupants in 20 dorm buildings received weekly data from meter readings on their energy and water consumption. Occupants in two buildings received real-time, web-based feedback on their usage. The process of providing the energy feedback to the students and the types of equipment used to report it are illustrated in Figure 5, below. The use of electricity in the 20 buildings dropped dramatically from the baseline period to the competition period, with the winning dorm reducing their consumption by 56%. Electricity consumption in the two buildings that received real-time feedback decreased by an average of 55%, when compared to a 31% average reduction in the other 20 buildings. The study included a cost benefit analysis that compared the cost of the required equipment, compared to the savings in dollars. In addition, an assessment of transferability of the technology and approach was included. Peterson, *et al.* (2007) stated that computer-based, socially normative feedback that includes energy data would also contribute to energy reduction at other colleges. In addition, they have provided assistance to a project in New York City that is working on using a similar system for an entire block of apartments. This study concluded that reducing electricity use by students in a dorm building is enhanced by providing feedback, education, and incentives.

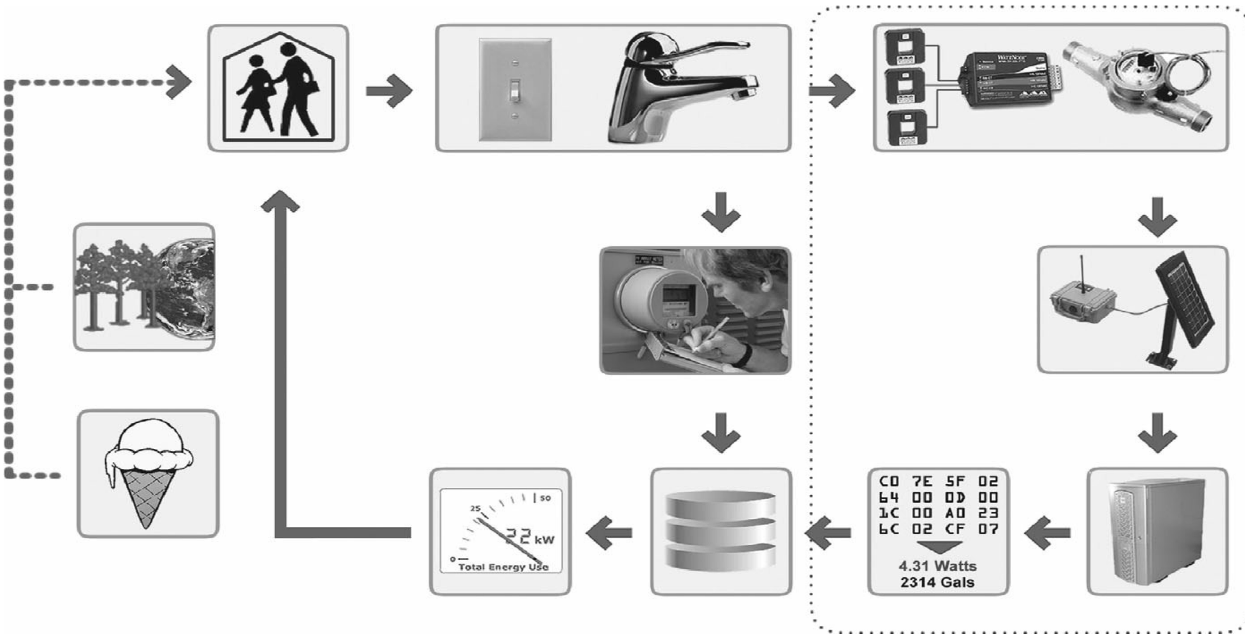

Figure 5. Diagram of feedback in college dorm (Peterson, *et al,* 2007)

Organization Scale

Providing data at the scale of an organization involves multiple building measurements. An organization might be a city with its own buildings scattered around town, a college campus with multiple buildings grouped on a site, or a corporation which may have buildings throughout the world. At the organization scale (i.e. colleges, corporations, etc.), there is very limited research on providing energy use feedback. It is, however, becoming more common to see energy-use feedback employed on college campuses. In most cases, the college is providing real time consumption data for some sub-set of the campus, such as the student housing or an environmentally-focused building (Turner, 2013). One example is the Ambient Orb, a device installed at Oberlin College which glows different colors in response to changing energy data. A current study involving all 54 campuses of the Minnesota State Colleges and Universities system (MnSCU, 2013), has demonstrated a reduction of total energy use for most campuses and the system as a whole. This occurred during a time when statewide use had declined, then risen (Figure 6). The feedback involves providing facilities and finance staff with ongoing access to a report showing energy use with monthly updates. The energy use shown in Figure 6 is in thousand British thermal units per square foot per year (kBtu/sf/year), and is the weighted average for all 54 campuses in the statewide system. The feedback in this case has not been consistent in its form, but it has been ongoing for five years. Initially, the campus leadership (college or university presidents and vice presidents) received quarterly updates. Eventually, all administrators saw energy performance comparisons as a part of regular monthly reports. As of mid-2013, a new website was launched making the updated monthly energy use for all 54 campuses available to the administration, students, and the general public (MnSCU energy use portal, 2013). The data is weather normalized and published in both formats.

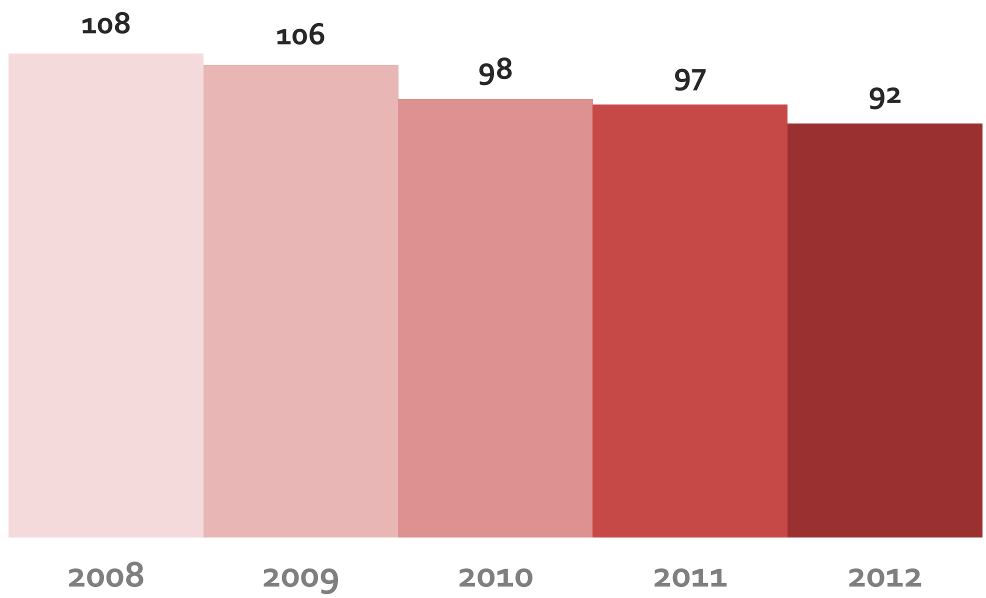

Figure 6: Energy use for MnSCU campuses (organization-wide) in kBtu/sf/year (MnSCU energy portal, 2013)

City Scale

Very limited research was found regarding the use of feedback at the city-wide scale. In one study linking policy outputs in city climate action plans with environmental outcomes, behavioral feedback in the home is listed as a key strategy in energy use reduction (Ramaswami, 2013). Referred to as "Innovative Behavioral Interventions," these strategies are expected to shape energy use in the future. In an earlier study by the same author, behavioral feedback (energy bills with social norming) produced measured average electricity savings of 3-4% city-wide (Ramaswami, et al, 2012). Several articles that focused on measuring city-wide GHG emissions discussed the impact of energy and its contribution to GHG emissions (Chavez and Ramaswami, 2010; Chavez and Ramaswami, 2012; and Hillman and Ramaswami, 2009). They suggested Btus per capita as a common measure for city-wide energy data use. No research was found on the impacts of reporting the data publicly to the cities or the constituents (residents and businesses).

Four recent energy use and GHG emissions reporting tools are attempting to use community-wide energy use data as a reported metric to provide feedback at a city scale. These are the STARS Community Index (STARS, 2013), International Council for Local Environmental Initiatives (ICLEI, 2012), Center of Neighborhood Technology's (CNT, 2013) Municipal reporting system, and Urban Land Institute of Minnesota's (ULI MN) Regional Indicators Initiative (MPCA, 2013). None of these tools has been in place long enough to draw any conclusions. Another system for reporting of total energy use at the city scale is the Carbon Disclosure Project (CDP). The CDP is a non-profit organization dedicated to assisting large companies and cities worldwide that measure, report, and manage their environmental impact. One of their largest accomplishments is the formation of the C40, a group of the world's largest cities dedicated to climate change leadership. In the foreword to the CDP 2011 annual report, suggesting the need for further study, Michael Bloomberg, Mayor of New York City and Chair of the C40 cities group, says "only by regularly and rigorously reporting and analyzing our efforts will we learn what works and what doesn't, and take effective action" (CDP Cities, 2011).

There are several cases where research suggests that measuring and reporting community-wide energy data is not the best approach, given that energy use for electric power generation often happens outside of the city's boundary (Ramaswami, et al, 2012). In all of the studies included in this research, the energy use is what is referred to as site energy, versus source energy. Ramaswami, *et* al, 2012 argued that the spatial scale of cities is quite small, given the large infrastructures in which they are embedded. In another study, the authors suggested that measuring and reporting energy use from only within the city's boundary (geographic method) could result in the unintended incentive to move energy consumption outside of the boundary (Chavez and Ramaswami, 2010). They suggested that a trans-boundary or consumption method would be better than a purely geographic method. These methods of measurement attempt to account for the full impact of the city's residents by taking into account the purchasing of products or services (such as energy production) that actually occur outside of the city's boundary. The same study also concluded that measurement tools (in this case, metrics for GHG emissions contributors) will play a significant part in the goal of developing low carbon cities.

Schmitt (2009) described the measures taken at the state level in Minnesota to quantify and report total building energy use as a subset of the state's GHG emissions. In this case, there is a clear target, mandated by state law, which can be tracked. One final study focused on GHG emissions, advocated for the measuring and reporting of consumption data at all scales from a local to national and global scale (Ostrom, 2009), referring to past successes, such as the reduction of air pollution levels in US cities. Ostrom (2009) also cited specific programs that utilities are implementing at a local scale that successfully use feedback as a method for reduction. College campuses, cities, and utilities around the country are adopting these programs.

Neves and Leal's 2010 study of ten local energy and climate action plans stated that local authorities are using the data collected for the purpose of evaluating a baseline, but are often not conducting ongoing monitoring. Their work assessed the indicators being reported at a city scale, including energy use in total and for each sector, per capita and per Euro. They make a case for more rigorous reporting of energy data at this scale. The authors reviewed 110 energy-based indicators and assessed their effectiveness when monitored and reported at the city scale. They then reviewed ten municipalities that use energy indicators to monitor progress towards targets in action plans. Their conclusion is that local authorities should collect and assess this data. Boswell, *et al.* (2010) reviewed 30 local climate action plans and their GHG emissions inventories. They stated that the documentation of data could be improved. They referenced the collection and publication of city-wide electricity and natural gas use obtained from utility companies, as a part of conducting GHG emissions inventories, and suggested it leaves little room for interpretation, since it is taken from meters. They conclude by saying that plans must use monitoring programs and state that only half of the plans they reviewed did this and most were inadequate, suggesting the need for more rigorous processes.

Although this literature review revealed many studies linking feedback to reduced consumption, these studies are mostly at the residential scale. The research is currently insufficient to support the assertion that reporting city-wide energy data will have the desired outcome of reducing energy consumption. As a result of these findings, the rest of this paper will examine the lessons learned from the residential-scale studies and attempt to determine how this information could improve the effectiveness of providing feedback at the community-wide scale.

Research question

What features of feedback from household-scale energy data can inform the process to effectively collect and report energy use at a community-wide scale to achieve conservation?

Methodology

Fifty sources were identified and reviewed because they contained information about providing energy use data at various scales. Thirty-nine of those were cited in the literature search as having some contribution towards the research question. In order to evaluate the relationship between the uses of feedback at the house/building scale to the city scale, eleven studies were assessed both qualitatively and quantitatively. Of those studies, five are primary and six are secondary research. They were selected based on the following criteria:

- Most recently published
- Included summaries of multiple studies
- Listed criteria for successful use of feedback to reduce energy consumption
- Included quantitative results given for studies
- Citation by other recent studies
- Included measurable energy use reduction

These studies were reviewed with the intent of finding patterns that could be repeated at other scales. In order to do this, characteristics and variables were identified and a master list was created. This list was then evaluated in terms of the frequency the items were identified and the relationship to successful studies in order to determine their effectiveness. These features are listed using bullet points to indicate the variables within each and briefly summarized with respect to their effectiveness. An assessment of their ability to scale-up is included in the conclusion section. The same eleven studies are also analyzed in terms of the type of study, the number of households, buildings or other studies reviewed, and the range of savings reached.

Finally, three tools currently using energy feedback at a regional scale were reviewed and assessed for the characteristics and patterns they contain that match those of the building-scale studies. The selection of these tools was based upon the references found in other studies reviewed.

Analysis and Discussion

There have been many studies conducted in the past twenty years to analyze the effectiveness of providing feedback to energy consumers in an attempt to determine the impact on reducing consumption. The vast majority of this research has been with single-family, residential households throughout the world. There are several examples of providing feedback in other scales, such as college dormitories, office, and institutional buildings. There do not appear to be any examples in the energy literature of providing energy use feedback at the community or city-wide scale and documenting the results to determine effectiveness in reducing consumption. One example not included in the literature search is the MnSCU data collection and reporting which has resulted in continuous reductions of use over the last five years. At the same time, the Urban Land Institute’s Regional Indicators Initiative (ULIMN RII) data for cities in Minnesota collected historical data that indicates a slight increase over the same time period.

The resulting energy savings in the studies reviewed in this paper range from 1% to 55% and average from 10% to 20%, compared to a baseline energy use. The baseline energy use in most of the studies is electricity only (refer to Table 1 and 2). There are a wide range of characteristics or features reported and analyzed in the literature regarding energy use feedback. The following is a comprehensive listing of those features, with a subset of the variables reported throughout the study set.

Features

1. Type of feedback
    - Direct feedback (immediate, real-time, from a meter or display monitor)
    - Indirect feedback (billing, usually monthly, processed in some way, i.e. historic comparison)
    - Disaggregated feedback (showing separate uses, such as heating versus lighting versus plugload)
2. Target of feedback
    - Household (single-family home owner and/or occupant)
    - Company/organization (leader, building operator and occupant)
    - City staff (building operator, elected official and occupant)
3. Additional information provided
    - Education (strategies to save energy)
4. Motivation (environmental information to explain why saving energy is good) comparison methods
    - To yourself over time (historical)
    - To similar group or average (normative)
    - To a target or goal (group or individual)
5. Frequency
    - Semi-annually or annually (occasionally)
    - Monthly or weekly (indirect)
    - Real-time or continuous (direct)
6. Timing/duration
    - Three month minimum (required for persistence)
    - Follow-up (after feedback)
7. Incentives provided
    - Monetary (reduced cost per unit of energy use)

- Non-monetary (recognition)
- Peer pressure (competition)

8. Billing types
   - Annual/quarterly/monthly
   - Direct debit (automatic withdrawal)
   - Disaggregated (shows separate uses)
9. Type of utility/usage
   - Electricity
   - All building energy sources
   - Indirect and transportation
10. Technology
    - Enhanced/processed billing (bills with additional information, such as historical information)
    - Website (home PC display)
    - Key pad meters/ambient display (such as the “energy orb”)
11. Cost of implementation
    - Total cost of providing feedback (equipment and time)
    - Cost per consumer (total cost divided by number of consumers)
    - Cost divided by savings (return on investment)
12. Community engagement
    - Engage consumer (owner and tenant, in design of feedback)
    - Engage community (through group reporting)

Assessment of effectiveness

The following is an assessment of the key features listed above, in terms of their effectiveness, based on the various studies reviewed. This section will focus on the effectiveness of the feature, based on the literature review. Table 1 is a list of the primary studies and table 2 is the secondary studies. The discussion follows the tables.

Type of feedback: The type of feedback appears to be one of the biggest factors in determining effectiveness at reducing energy consumption in the sample studies. The most common assessment of this feature or characteristic is that direct feedback resulted in a 5% to15% savings while indirect feedback resulted in a 0% to 10% savings (Janda, 2009). It is important to note that indirect feedback is defined as a bill that is processed in some way. An example of this is a bill that shows comparative results (Roberts and Baker, 2003). One reason that is given for the reduction found to occur with only indirect feedback is the comparison to other types of consumer usage and payment methods. For example, if a person went to the grocery store, no items were priced and they only paid when they received a bill in the mail each month, it would be very difficult to control consumption (Fischer, 2008).

Target of feedback: It is important to note the intended recipient of the energy use feedback. Since almost every study reviewed as a part of this research is residential in nature, the target of the feedback is likely the homeowner or residents. In the case of community-wide feedback, the target could be the users of energy (business owners, employees, and residents) and/or the city leaders (staff and elected officials). The literature did not demonstrate that the target was able to have a strong impact on the reduction. Table 3, Characterization of the User, is a set of observations regarding the recipient of the feedback at each scale.

Additional information provided: Several studies emphasized the importance of providing additional information, such as education about environmental issues and/or providing strategies for energy use reduction (Fischer, 2008; Bin, 2012; Peterson, *et al*. 2007; Brandon and Lewis, 1999; and Ueno and Nakano, 2006). According to one study, only 12% of the general public understands energy to the extent that they connect their actions directly to consumption, which suggests that 88% need to have more information in order to make substantial changes (Janda, 2009). One study used a control group where no additional information, such as providing energy reduction strategies, was given. Both groups received the same type of energy use feedback, but the group receiving additional information had significantly higher reductions (Abrahamse, *et al*. 2007).

Comparison methods: Most of the direct feedback residential studies use the comparison to energy use over time, sometimes referred to as a baseline. This is made more complicated by the need to weather normalize in order to get comparable data. Indirect feedback in many of the reviewed studies use a comparison to a similar group or average (normative). For example, the energy use of one household compared to other households in that neighborhood. This is a method that encourages friendly competition through peer pressure. Few studies to date have used a target or reduction goal as the comparison method. Most of the studies use a normative comparison, which suggests that it is more effective than other methods.

Frequency: This method is in part established by the feedback type because direct feedback is usually provided in real-time. Indirect feedback can be semi-annual, annual, monthly, weekly, or daily. Based on the results of the studies reviewed (Tables 1 and 2), there is a direct correlation between the frequency of the data collection/reporting and the reduction of the energy use. The more often the user sees the data, the greater the reduction (Fischer, 2008).

Timing/Duration: There were examples of research that show a need for the feedback to be provided for a specific period of time in order to be effective. In one case (Darby, 2006) the time period that appeared to be a minimum was three months. This feature is sometimes referred to as persistence. Darby, 2006 suggests that providing feedback should be continuous and that only after a year is the behavior change persistent.

Incentives provided: Incentives, such as money or other non-monetary items such as pizza or ice cream, appeared to make a difference in the short term, but not in the long run (Peterson, *et al.* 2007). There is not an obvious relationship between providing incentives and reducing energy use. In the cases reviewed, the incentives were based on actual energy use reductions.

Billing types: The type and frequency of billing has been shown to be a characteristic of feedback. In the case of a direct debit billing process for a residence, the act of providing indirect feedback such as processed monthly billing can make a significant difference. This is due to the fact that with some billing types, like direct debit, the consumer has no knowledge of their level of use. More enhanced billing, even on a monthly scale, can provide more actionable information.

Type of utility/usage: A number of the studies analyze the use of feedback only with respect to one utility type: electricity (Fischer, 2008). The reason for this may be the simplicity of reporting one metric, such as site kilowatt hours (kWh). In order to report total energy use, kWh, therms, etc.) units would need to be converted into British thermal units (Btu). In terms of the calculations required, this is a relatively easy conversion to make. However, in the case of a resident, the two utility types are often coming from different utility companies, so there is no one entity to do the conversion. Some of the studies address other usage outside of building energy, such as transportation or indirect usage for things like purchased products. These items are outside the scope of this study.

Technology: The ability to report energy use data at certain frequencies in the residential studies appears to be dependent on technology. In addition to the use of the personal computer, using specific software for real-time meter reading and key pad meters are critical (Darby, 2006).

The use of the ambient display, called the “energy orb”, in the dorm competition demonstrated the most interesting—if not the most effective—approach (Peterson, *et al.* 2007).

Cost of implementation: Some of the studies discuss the element of cost and indicate the increase in cost relative to the frequency of information (Bin, 2012). In one case, the specific costs are given and the payback, or return on investment (ROI), is calculated and shown (Peterson, *et al.* 2007). The purpose in this case was to illustrate that enhanced metering has a great deal of potential for future savings based on the results from the control group of 20 buildings, versus the two buildings that used it, but that it comes at a cost.

Community engagement: Several of the studies suggest involving the users in the design of the data collection and reporting method. In one case, the author suggests that this will increase its effectiveness (Roberts and Baker, 2003). One example of this is conducting a survey or focus groups to test various methods of feedback on the user.

Ability to scale up features

It is difficult to assess whether or not features could be scaled up for a community-wide program without implementation and assessment. There are differences between communities and homes that help establish some context. Table 3, Characterization of the User, is a matrix that compares various aspects of the feedback provided, such as the end user, the party that pays for energy and the types of energy with feedback being provided, based on the various scales in the studies reviewed. It is informational in nature and helps explain the contracts between the groups being compared. Major similarities include utility sources and diversions include technology and level of control.

Significant differences in the user are noteworthy. The owner of a home has almost complete control over the use of energy, while no one individual or group has that level of control for a city. In addition, there is a current mechanism (utility billing) for measuring the energy use in a home, while there is not in a city. As discussed, many cities have specific goals for at least GHG, if not energy use reductions, while most homes do not.

Table 4, Analysis of Feedback Mechanisms, is an assessment of the various feedback mechanisms at each scale, indicating the level of energy use reduction observed at that scale in the various studies reviewed. In most cases, the feature appears to have some impact at a household scale, while the impact at the city-wide scale is unknown.

Table 4 **Analysis of feedback mechanisms (characteristics) used in energy conservtation programs**

This Table is an assessment of the potential to reduce energy consumption at a given scale by using the particular characteristic indicated. High is an indication of strong potential to decrease energy use. Medium indicates a potential to reduce consumption. Low represents a minimal or minor potential for reduction. The remaining catagories are not applicable and Unknown. The Analysis and Discussion section Includes a description of each of the Characteristics listed below.

H	High	Decreased use
M	Medium	Can affect use
L	Low	Minimal affect
NA	Not Applicable	
U	Unknown	

CHARACTERISTIC		SCALE HOUSE	BUILDINGS	ORGANIZATION	CITY
Type of feedback					
	Direct feedback	H	H	M	L
	Indirect feedback	H	M	M	L
	Disaggregated feedback	H	NA	NA	NA
Target of Feedback					
	Household	H	NA	NA	L
	Company leader	NA	M	H	NA
	City staff or elected official	NA	M	M	U
Additional information provided					
	Education (Strategies to save energy)	H	M	M	U
	Motivation (Environmental Information)	M	M	M	U
Comparison methods					
	To yourself over time	H	H	H	U
	To similar group or average	H	M	H	U
	To a target or goal	M	M	M	U
Frequency					
	Semi-annually or annually	L	L	L	U
	Monthly or weekly	M	M	M	U
	Real-time or continuous	H	H	NA	NA
Timing/Duration					
	Three month minimum	M	L	L	U
	Follow-up	U	M	M	U
Incentives provided					
	Monetary	L	L	U	U
	Non-monetary	M	M	U	U
	Peer pressure	M	M	M	U
Billing types					
	Annual/quarterly/monthly	L	M	M	NA
	Direct debit	U	U	U	NA
	Disaggregated	M	U	U	NA
Type of utility/usage					
	Electricity	H	H	H	L
	All building energy sources	M	M	M	L
	Indirect and transportation	L	L	L	L
Technology					
	Enhanced billing	M	M	M	U
	Website/home PC display	H	H	U	U
	Key pad meters/ambient display	H	H	U	U
Cost of implementation					
	Total cost	U	M	U	U
	Cost per consumer	U	L	U	U
	Cost divided by savings	U	M	U	U
Community engagement					
	Engage consumer in design of feedback	M	M	M	U
	Engage community through group reportin	L	U	U	U
	Use of focus groups	L	L	L	U

The following is a list of the features of feedback from the section above and an assessment of the issues that would be confronted in scaling up to the city-wide program. Based on a numerical assignment of points based on high, medium, and low for Table 4, the top four features for a successful use of feedback in order of effectiveness are: comparison method, type of feedback, technology, and frequency.

- Comparison methods: In the case of household, building, and organizational scales, this characteristic demonstrated the highest ability to reduce energy consumption. Whether comparing to yourself over time, to a group of similar users, or a target, these types of feedback showed strong potential at the building scale. There were no examples of applying these types of comparisons at the city-wide scale in the literature reviewed for this paper.
- Type of feedback: Based on the literature reviewed, the type of feedback seemed to be the strongest characteristic at the household scale. Not all types of feedback were applicable at the building and organization scale. Since direct feedback is a result of a real-time metering such as in home direct displays (Darby, 2006), it may be difficult to provide at the city-wide given current technology. Indirect feedback could be provided along with other communication, such as billing or via websites.
- Technology: Using meters that are visible in real-time by displaying the output or using home-based PC's, technology drives the potential for reduction at the household and building scales. Far less is known about how technology might affect the potential for reduction at the city-wide scale. Using technology to deliver and enhance energy use information at the city scale may allow for feedback more often than annually. Most examples of technology to deliver feedback at the household scale and in the dorm example (Peterson, *et al*. 2007) involved real-time meters in individual units or houses. This may be prohibitively expensive in a city-wide application.
- Frequency: Although not as strong as the three characteristics above, frequency clearly has the potential to influence energy use reduction, particularly at the household and building scale. It is difficult to say what frequency limitations there are in providing this information at an organization or city-wide scale, since very few examples of this were found in the literature. Examples of city-wide reporting found in the literature were primarily annual. Monthly data may be possible, although no cases of this frequency at a city-wide scale were found.
- Timing and duration: Feedback at the household scale has caused energy use reduction to persist after only three months. If energy feedback were to be provided at the city scale, a longer period of time may be required to develop persistence.

- Target of feedback: This feature varies dramatically by scale and could be quite diverse at the city-wide scale. Additional research will be required in order to understand the impact on energy use reduction.
- Additional information: This feature is relatively easy to implement at a larger scale using direct mail, utility invoice supplements, publications, and websites. It may be more difficult to know if the information is reaching its intended audience.
- Incentives: Cities are able to consider and offer additional incentives, monetary or otherwise. Seeing one's performance compared to others (household or city scale) may itself be an incentive by creating competition. It is unclear whether incentives could be provided effectively at a city-wide scale, since there are no known examples. Some cities have requirements based on provided resources, such as St. Paul, MN Green Building program.
- Billing types: One possible application at the city-wide scale for this feature of feedback is some type of combined effort. For example, the community that is receiving the energy use data for the entire city also has a more frequent and enhanced billing type for residents and/or businesses. This concept will be discussed further in the Conclusion/Recommendation section.
- Type of utility/usage: Using individual utility types or combining them at the city scale does not appear to be difficult. Examples of metrics for community wide energy use are site kBtu/household for residential and kBtu/square foot for commercial (Chavez and Ramaswami, 2010).
- Cost of implementation: Due to the nature of a larger-scale project, costs will likely go up. Any methods with a high cost of implementation at a community-wide scale would likely decrease the chances of participation. The impact and relationship to cost is relatively unknown at most scales.
- Community engagement: It may be more difficult to engage users in the design of the systems at a community-wide scale. Involving a representative group, for example through a focus group method, may be feasible.

Limitations

In order to evaluate the effectiveness of various characteristics of energy use feedback and attempt to determine the ability to scale up to the city-wide collection and dissemination of data, studies from around Europe and North America were reviewed and analyzed. The vast majority of the research to date has been completed on residential households (Bin, 2012) and the number of households included in each study is fairly limited. The very few studies found focusing on other building types had even smaller data sets. Most studies were conducted within specific climate zones and may require additional weather normalization to be compared to one another. These limitations suggest that more research needs to be done with commercial, industrial, and institutional users, and that the pool of users in the studies needs to be increased.

Conclusion

There were no studies found during this research where providing energy use feedback at the city scale was done with more than annual frequency or measured for the impact on energy use reduction. Therefore, it is not clear whether providing city-wide energy feedback will result in a reduction in energy use. Energy use feedback has been repeatedly demonstrated to have an impact on reducing consumption when provided to households frequently and with supporting information in a clear and understandable format. There have been numerous studies showing reductions in the range of 2% to10%, based on providing indirect feedback, usually in the form of processed enhanced billing. The savings typically increases to the 5% to15% range when the feedback is provided in real time. The few studies using commercial and institutional buildings indicate similar results. Although many of the studies are small, they tend to have similar results. In cases where the user has limited feedback, such as with a college dorm, the same types of feedback resulted in significantly greater saving—in the 32% to 55% range.

Based on the review of a number of the studies documenting the positive results of providing feedback to reduce energy at the residential scale, efforts to use city-wide energy reporting should incorporate the features best known to enhance effectiveness. The features that appear to have the greatest impact include: providing feedback with a normative comparison in direct or indirect form, using meters or web-based displays, and offering feedback in as close to real time as feasible. Most features appear to be effective at the household scale, but the effectiveness at the city scale is unknown.

It is clear that providing energy use feedback alone to household and occupants of college dormitories with the appropriate features is an effective method for reducing energy consumption. Considering the lack of studies of using energy feedback at large scales, such as cities and organizations, additional research at these scales could offer valuable insight. Cities are nimble and have the power and tools to affect change.

The primary challenges of providing energy use feedback at the city-wide scale, or key ways in which they differ from the household or residential scale are:

- Who pays for the energy use? In the case of the city, any individual homeowner, resident, business owner, or employee pay only a fraction of the total city-wide energy cost. This may limit the benefit to them as stakeholders.
- Who receives the feedback? At the household scale, the owner and occupants receive the feedback and are in direct control. In the city-wide example, we are not yet sure how the feedback can best be distributed.
- What is the level of control? At the household level, the occupants and/or owner are in direct control of the consumption. In the city-wide case, no one has a significant level of control. The city, through policy, may be the most influential.
- What technology is most useful? While the use of displays can play a very important role in the household, at the city scale, further study is required to determine the format and level of influence.

All of these challenges may be overcome and require additional study.

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APPENDIX A-1

Climate Change Mitigation, Adaptation and Resilience: Proposed Policy Direction

For confirmation August 28, 2013

Overall direction

The Metropolitan Council will explicitly address issues connected to climate change mitigation, adaptation and resilience in *Thrive MSP 2040* by using climate impacts as a lens through which to examine all of its work. The Council has already made significant strides in addressing climate change impacts through its operational sustainability policy; with *Thrive MSP 2040*, the Council will incorporate climate change impacts more systematically and intentionally in its planning work, including both *Thrive MSP 2040* itself and the *Thrive* systems and policy plans.

With this lens, the Council will look for opportunities to use both its operational and planning authorities to plan for and respond to the effects of climate change, both challenges and opportunities. This will include, but not be limited to, parks and open space, transit, transportation and land use, wastewater treatment, and water supply.

Greenhouse Gas Emission Reduction Goals

Thrive MSP 2040 will reference the state's goals for greenhouse gas reduction that were adopted in 2007. The Council will explore how to monitor regional greenhouse gas emissions to identify opportunities to encourage greenhouse gas reductions.

The Council will create incentives to reward local governments that set and make progress on local greenhouse gas reduction goals. The Council's approach will focus on positive approaches unless and until:

- The region is at foreseeable yet avoidable risk of falling out of air quality attainment status with the Environmental Protection Agency; or
- The collective financial cost to the region of non-action would justify the Council taking a stronger approach of mandating changes in local behavior; or
- Further analysis identifies a critical need for additional regional action.

Information and technical assistance to support regional and local climate change planning

The Metropolitan Council will expand the information and technical assistance it provides to local governments to support regional and local climate change planning and assist local governments:

- The Council will develop expertise in developing, collecting and disseminating information about climate change, including energy and climate data, the next generation of the Regional Indicators data, and a regional greenhouse gas emissions inventory.
- The Council will also provide technical assistance to the region's local governments, including identifying risks, best practices and model ordinances for climate change mitigation and

adaptation and working in partnership with the MPCA's statewide Minnesota GreenStep Cities program.

The Council will provide information to local jurisdictions about the risks of not responding or preparing for climate change and encourage local governments to plan and prepare for climate change, including incorporating climate change planning into their local comprehensive plans.

Additionally, the Council will collaborate with regional leadership and convene local governments and the broader community to address climate change mitigation and adaptation within the region. These expanded roles in information and technical assistance will help the Council be a resource to both local governments and the region at large. The Council intends to be a prominent player in elevating this important issue that affects the long-term viability of the Minneapolis-St. Paul region.

Additional detail about climate change risks, mitigation, adaptation and resilience will be developed and adopted in the Regional Parks and Trails Policy Plan, the Transportation Policy Plan, the Water Resources Policy Plan, and the Water Supply Master Plan.

Revised August 22, 2013

Table 1
Primary studies

		Quantitative Findings				Feedback Features											
Study	**Type**	**Year**	**Scale**	**Size/location**	**Results**	**Type**	**Target**	**Additional Information**	**Comparison**	**Frequency**	**Duration**	**Incentive**	**Billing**	**Utility**	**Technology**	**Cost**	**Comments**
Peterson et al	Primary	2007	Dormitory	22 Buildings/ Oberlin, Ohio	32% less	Direct & Indirect	Student	Education	Normative	Real time & weekly	Five Weeks	Party	None	Electricity	Automated monitoring	$250k	A study of 22 dorm building at Oberlin College, comparing direct (real time) and indirect (weekly) feedback to students.
Brandon & Lewis	Primary	1999	Household	122 Homes/ Bath, UK	7% less	Indirect	Resident	Questionnaire	Multiple Normative & Historic	Monthly	Eight Months	None	Monthly	Electricity	Mailings and PC's	NA	A study of 120 homes in Bath UK provided with energy use information in 1996. The primary conclusion was that providing data on a PC was the only effective methoc
Ueno et al	Primary	2005	Household	19 Homes/ Osaka, Japan	12% less	Direct	Resident	On screen strategies	Normative	Daily	28 days	None	Monthly	Electricity and gas	Interactive computers	NA	A study of 19 households in a neighborhood in Japan ten homes were in experiment with feedback and nine in control group.
Ueno et al	Primary	2006	Household	9 Homes/ Osaka, Japan	9% less	Direct	Resident	On screen strategies	Normative	Daily	16 weeks	None	Monthly	Electricity	Interactive computers	NA	A follow-up to the 2005 study using ECOIS software. The study involved an eight week baseline and an eight week experiment.
Abrahamse et al	Primary	2007	Household	189 Homes/ Grogningen, The Netherlands	5.1% less	Indirect	Resident	See comments	Normative	Semi-monthly	5 months	None	Monthly	Electricity	Mailings	NA	This was a study where the group provided enhanced billing information had less knowledge about energy savings strategies than the control group, who had less savings occur.

Table 2
Secondary Studies

		Quantitative Findings				Feedback Features								
Study	**Type**	**Year**	**Scale**	**Size**	**Results**	**Type**	**Target**	**Additional Information**	**Comparison**	**Frequency**	**Duration**	**Utility**	**Technology**	**Comments**
Armel *et al*	Secondary	2012	Residential	18 Studies	3.8-12% less	Range	Resident	No	Studied	Studied	Studied	Electricity	Studied	A review of 18 studies, focused on the disaggregation of end use data, especially at the appliance level.
Fischer	Secondary	2008	Households	26 Papers	1 - 20% less	Range	Resident	Studied	Studied	Studied	Studied	Electricity	No	Research on five studies (including four from Table 2) and 21 original papers (including three from Table 2) on the effect of feedback on electricity consumption.
Darby	Secondary	2006	Households	30 studies	0-15% less	Direct & Indirect	Resident	No	Studied	Studied	Studied Persistence	Electricity and gas	Studied	Review of 30 primary studies on providing feedback to residential energy users. Focus primarily on the relationship of results to persistence and feedback type.
Faruqui *et al*	Secondary	2010	Households	12 pilot programs	2.5-18% less	Direct	Resident	No	No	No	No	Electricity	All in-home displays	A review of 12 studies conducted In Japan and North America from 1998 through 2009. The type of feedback was from in-home displays for direct feedback and types of payment.
Bin	Secondary	2012	Commercial	3 studies	Up to 20% less	Direct	Occupant & Operator	Studied	No	All Real time	No	Electricity	All digital dashboard	A study of energy behavior programs in the workplace with a section on feedback. Analysis of three recent studies of feedback in commercial situations.
Roberts & Baker	Secondary	2003	Households	34 studies	Over 20% less	Direct and Indirect	Resident	No	Studied	Studied	No	Electricity and gas	Studied	A review of 34 studies involving multiple methods of normative and feedback types in residential energy feedback results.

Table 3 **Characterization of the User**

This Table identifies the difference between providing feedback at the various scales covered by the studies.
It is not an analysis, rather a set of observations about the feedback provided with an emphasis on the users or receiver of the feedback.

End User	**Scale** **HOUSE** **Residential**	**BUILDINGS** **Commercial/Industrial**	**ORGANIZATION** **City, campus, corporation buildings**	**CITY** **Overall**
WHO RECEIVES THE FEEDBACK	Occupants of the house	Building operator and possibly tenants (occupants)	Building operators, management and possibly occupants	All parties, homeowners, city, and companies.
WHO PAYS	The homeowner, usually also the the occupant and purchaser of equipment	The building owner and sometimes tenants.	The city and therefore taxpayers.	All parties, homeowners, city, and companies.
FEEDBACK TYPE	Direct Indirect Dissaggragated	Direct In-Direct Dissaggragated	Indirect Dissaggragated	Indirect
UTILITY SOURCE	Gas, electricity, propane and district energy	Gas, electricity, steam, chilled water and district energy.	Gas, electricity, steam, chilled water and district energy.	Gas, electricity, steam, chilled water and district energy.
% ENERGY USED BY SCALE	40% Average consumption by residential sector based on RII data	58% Average consumption by commercial/industrial sector	2% Average consumption by public buildings within the city boundary	100% Total energy used in an given city or community
LEVEL OF CONTROL OF PRIMARY RESPONSIBLE PARTY	High The homeowner may guide the construction, is occupant and purchaser of equipment.	Medium The building owner may guide construction, and may be an occupant.	Medium City staff guide construction and most occupants are city staff. City buys equipment.	Low There are many variables and no individual with any high level of control
TECHNOLOGY	Technology in the home could involve the use of PC monitors, real time meters connected to usage and displayed for occupants.	Technology in the home could involve the use of PC monitors, real time meters connected to usage and displayed for occupants.	At the organization scale, technology has primarily been web based, with some individual building metering, similar to the previous two columns.	The technology found for cities appeard to be limited to reporting through websites and written reports.